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THE DEVELOPMENT OF A SMALL TO MEDIUM IRON ORE MINE

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THE DEVELOPMENT OF A SMALL TO MEDIUM IRON ORE MINE

by Oscar de Oliveira
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1 - BRAZILIAN IRON ORES

(a)-The principal and best-known iron ore formations in Brazil are the deposits in the "Quadrilátero Ferrífero", the "Iron Quadrangle" in Minas Gerais, covering an area in excess of 6 000 sq km and containing over thirty billion tons of iron ore of various types and qualities. The very valuable work of general geological reconnaissance was undertaken in the last fifteen years by Brazil's National Department of Mineral Production (DNPM) and the United States Geologic Survey team, supported by Point IV [a]. A large amount of detailed study remains to be done for future generations of geologists and mining engineers.

The ore is commonly divided into the three principal classes: soft itabirite, hematite and canga. The hematite is classified into hard and soft hematite. The soft itabirite contains anywhere from 35% to 65% Fe and its major and only significant impurity is quartz. This ore is not yet a commercial ore, requiring extensive beneficiation to eliminate the quartz and raise the Fe tenor to over 65%. However, due to its unlimited reserves and easy mining, the itabirite will certainly become a commercial ore in the very near future. An active research for economical processes has been under way for the last four years.

The high grade hematite is of quite uniform quality and ranges in tenor from 66 to 69% Fe. Quartz and sometimes alumina are the only important impurities. The phosphorus content is usually below 0.05 percent. The hematite, both soft and hard, is presently the only export ore ranging in price FOB Brazilian Port from $7 to $ 12. The "canga" is a porous and resistant ore usually found at the surface and is derived from the weathering of itabirite. The average thickness may vary from 1 to 10 m. The Fe content ranges from 45 to 65%, with impurities of silica, alumina and phosphorus. The latter impurity (over 0.1%) prevents its use as export ore unless blended with other ores, but is being consumed domestically in charcoal blast furnaces.

(a) DNPM and USGS, "Outline of the Geology of the Quadrilátero Ferrífero, Minas Gerais, Brasil" (DNPM, Rio de Janeiro, 1959).

(b)-Most of the 7 000 000 tons of Brazilian iron ore exported in 1961 is compact hematite with reduced amounts of fines (generally less than 25% under 1/2") These ores, classified according to gradation into lump, pebble and rubble, will gradually become a minor portion of export ores, as cheaper maritime transportation will undoubtedly bring the cost of fines and run-of-mine ores down to competitive levels.

The major ore exports are handled through the ports of Vitória (over 5 000 000 Tons) and Rio de Janeiro (1 100 000 tons). The ore, ship-loaded at Vitória, is mined and transported from Itabira, 570 km inland over a narrow-gage rail by the Cia. Vale do Rio Doce. This company is a corporation with a majority participation (90.7%) from the Federal Government of Brazil, and the remainder 9.3% from private investors. At the present time the following ores are being mined and sold

		% Fe	% P	Humid. %	Grad.	ers. %
L	Lump	68.5	0.045	1	8x1/2	10
LS	"Special"	68.5	0.045	1	8x 2	20
RM	Run-of-mine	64-67	0.05	2-4	8x1/2	40
P	Pebble	64-67	0.05	2-4	3x1/2	25
G	Gravel	64-67	0.05	6	3x1/2	60
F	Fines	60-67	0.08	3-6	1/2x0	-

Although on the surface the physical layout of ore mines are very similar to those in other countries, the problems to be faced in Brazil are quite different. These problems and the attempts to overcome them are the basic subject of this paper.

2 - FACTORS AFFECTING MINING OPERATION

The efforts of the Brazilian Government and industry, especially in the last decade have resulted in a very rapid rise of industrial capacity, degree of mechanization and the use of modern technology. The Brazilian manufacturing and service industries present an extreme range from highly mechanized, sometimes automated operations to the most primitive processes using century old manual methods. The phenomenal growth in industry capacity, however, has not been accompanied by a parallel increase in labor ability and capacity. The basic requirements for a compatible educational level and physical state of health of personnel imposed by the more complex technological demands have not been met in the same proportion as these technological advances. Specifically, the divers problems facing the Vale do Rio Doce in its mining and transport operations of iron are as follows:

(a)-Labor : the distance of the ore body from industrial centers and situated in a relatively virgin and inaccessible region reduces the local availability of labor to practically nil. This is not an uncommon problem for mining operations, as it is the rule rather than the exception that locates the high grade

deposits in faraway undeveloped interiors (b). It becomes therefore necessary to construct new townsites, provide social services and amenities to attract imported labor and prevent too large a turnover. However, the planning for a long-range operation must include the evaluation of labor capability and efficiency, and more important the probable rate of improvement of the labor capability and efficiency in the next 5, 10 and 20 years. The increase of literacy and skills whether caused by the general regional improvement of educational standards or Company-induced schooling and training facilities, must be taken into account not only in the progressive mechanization of mining operations, but phased into the proper depreciation and obsolescence schedule of equipment. It can be said without fear of contradiction that completely unskilled labor is in oversupply and per-man-cost is about $30 monthly. It is also true that this labor performs with low efficiency in anything but simple and manual operations. This situation is not helped by the shortage of intermediate supervisory skilled labor and foremen, capable of controlling and instructing a large unskilled labor force. And finally the scarcity of experienced technical and managerial personnel intensifies the organizational problems.

(b) - Equipment - Until fairly recently, all equipment and tools were imported over a long distance from the U.S. and Europe. As Brazilian industry increases its output from small tools to medium size equipment, and is now initiating the manufacture of heavy equipment, the selection of mining equipment, parts inventory, becomes more and more a critical part of the operations. With an all manual-labor operation the continuity of ore supply is rather constant and risk of breakdown is minimum, and deficient production can be made up by additional labor and small tools. However, considering an average manual production of 8 to 12 tons per day laborer, the capacity of ore production soon reaches a limit as working space runs out and the social obligation of providing decent subsistence becomes overwhelming. Therefor mechanized mining becomes mandatory whenever the annual production of a single mine exceeds say 500 000 T.

(c) - Market distance - The principal markets of our iron ore is Japan, Europe and the United States, all in the Northern Hemisphere. In addition to the long maritime distances, the mining districts themselves are located 570 km away from the port, thus imposing on the Company a railroad operation of major magnitude. This inherent handicap can be overcome only by improving bulk transport methods and high-efficiency operation in order to lower the costs to competitive levels. It becomes thus principally a technical problem of increasing transport capacities by better and more powerful traction, longer trains, larger loading facilities and finally the employ of super-carriers. The dimensional increase of cars, trains and ships is compatible with the Brazilian labor situation, as the substantially same number of skilled operators properly trained can handle equipment of larger capacities.

(d) - Capital Investment - The requirements for capital in an industrially expanding country can rarely be met by the internal money market exclusively. This problem is not native nor particular to Brazil, but is extremely acute due to

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(b) Orinoco, Seven Islands, Cartier, Toquepala and many others.

the economic-political situation, which is not conducive at the present time for large scale private foreign investments. The inflationary economy and the limitations of legislation have made expansion capital rather scarce.

3 - ANALYSIS OF A MINING OPERATION

It will not be asserted here that the solutions for the above-cited handicaps have been found, nor that the manner in which the problems are being treated is the final and absolute answer. This paper will describe the past and present attempts in using modern science and technology for the improvement of a part of Company's operations.

(a)- Present Mining Operations - The Vale do Rio Doce is presently operating and opening up for operation five iron ore deposits spread over 8 km. More are scheduled over 50 km away. The ore body reserves per mine range from 100 000 000 T to about 30 000 000 T and the production rates range from 3 000 000 T down to 600 000 T annually. The ore mined is all hematite, from hard, compact and abrasive to soft, powdery ores. The ore bodies vary greatly in geological characteristics, homogeneity and iron tenor. The consumers, all non-captives, require specific gradations in variable quantities. The compliance of these various needs require strenuous coordinated efforts of mining, stockpiling, loading and transporting via the railroad to the port, the right quantities of ore, in such a manner that the ore-carriers can be loaded promptly and with the specified ores.

In the earlier years, when quantity and diversity of ore types were reduced, the entire operation can be based on a relatively few skilled operators and managerial personnel. However, the ever increasing production and sales, coupled with the corresponding lack of required additional experienced personnel compelled us to resort to other means to circumvent technician shortages.

(b)- Specific Problems : In order to operate thecompany in a competitive market, the management must be able to:

(i) - obtain exact information on all company's operations immediately, such as stockpile quantities, types of ore, loading requirements, train scheduling, etc.
(ii) - react to changes of market demand quickly by modifying mining, beneficiation and transporting operations.
(iii)- synchronize all mining operations at optimum level, i.e. by not permitting each separate mine to pursue a course of action which might be the most desirable for it, but instead determining the most profitable operation for the integrated mining system.
(iv) - provide technical and operational assistance rapidly and economically, such as proper equipment selection.
(v) - maintain up-to-date cost data and surveillance over all operations, to determine the best cost-price relationship and production quantities.

(c)-Flexibility - The multiple operations, as stated above, require flexibility of a large degree. At the same time equipment will last for a certain determined period thus resisting radical changes in operations. And again, labor, due to the slow process of up-grading, will naturally resist quick changes in operations. Consequently the necessities become rather obvious:

(i) - Equipment, at the expense of individual efficiency, must be standardized to a greater degree, than may be indicated in Europe or the U.S. Interchangeability of parts and components will reduce inventory and abate the pressure for more skilled mechanics and operators.
(ii) - Central stores, to effectively control and reduce the amount of inventory.
(iii) - Training centers to provide instructions for operators of more complicated equipment, supervisory and future management personnel.

(d)-Computor : High speed electronic computors can be effectively used to overcome at least a part of the deficiency of technical personnel. The application of the linear programming technique to the solution of our problems is considered one of the best and most versatile technique capable of evaluating alternative courses of action. The linear programming approach permits systematic determination of the best optimum combination from a large number of alternatives and is characterized by high computational efficiency. Therefor the programming formulation can be readily used to develop an array of optimum plans for mining, transporting, loading and selling, covering a whole range of foreseeable conditions. For the analytical study of the existing operations the mathematical description of the individual functions and their interrelations serve to provide a frame work for investigating how the operation would react to variations of different internal and external factors, such as cost fuel, labor cost or sale price of ore, etc. Most of the problems involve the selection, utilization and scheduling of equipment, materials and shipment in order to achieve minimum operating costs, optimum equipment combinations, maximizing profits, optimum ore mix for maximum profits.

4 - PROGRAMMING AN ORE MINE OPERATION ON A MEDIUM-SIZE DIGITAL COMPUTER

(a)-Purpose - The establishment and operation of an ore mine involves a complex of many linear programming type problems and comprises:

(i) - Formulating the problem and
(ii) - Performing the detailed arithmetic computations.

The latter eliminates the task of performing the many necessary detailed calculations. Step (i) still requires the use of a trained and experienced techni - cian to develop the following data:

a - flow chart presentation of the operation.
b - establishment of a known definable objective or criteria, i.e. grades of ore, quantities, market requirements, etc.
c - define all restrictions and limitations on the extent of the problem, involving gathering of all data, identifying all variables, their respective coefficients of physical or economic nature.
d - express the objective function in algebraic form terms of unknowns with explicit coefficients. Then, express the limiting functions in terms of the same unknowns as in the objective functions, arriving at a combined set of equations and a mathematical model to be processed on the computer.

(b) - Formulation - The formulation of an actual mining operation is herewith presented in a very much abbreviated form:

(i) - A Flow Diagram must be established representing the entire operations for the several mines and establishes a basis of the necessary framework for the analyst.

(ii) - Factors affecting the Operations must identify and define all constants, variables and coefficients, constraints and limitations. These are:
a - Location of the mines with reference to transport routes and loading terminal.
b - Geological Description of the mines with cross sections of the ore bodies and types of in situ ore.
c - Mining Operations are based on open pit mining benches of 6 to 12 m high and annual production of 800 000 T and 4 500 000 T; two 8-hr shifts for excavation, hauling, crushing and loading and one 8-hr shift for drilling with blasting occurring once a day between shifts.

i. - Drilling and blasting and necessary equipment depend on density of ore, types to be encountered, abrasiveness, bit and drill steel life and other factors, such as properties of terrain and amount of waste material. The type and operational cost of equipment is investigated and tabulated.
ii - Loading units depend on cost per cubic meter handled, job conditions and economic conditions.
These items are influenced by total volume handled, cost of the equipment, operating and labor costs, operating range, dipper size, digging force at tooth point, time allowable and hauling unit size. In addition, economic conditions may become a deciding factor because of available capital and its cost, investment caution due to uncertainty of production rate, availability of used machines, etc.
iii - Hauling units are a somewhat lesser problem because deficiencies can be remedied by additional units, which is not the case with loading machine. However, it is important to determine size, number of units, down time, standby, synchronization through traffic control, body size, tire types, etc.

iv - Crushing and Screening and selection of equipment is made and all data graphically assembled; the following factors have an important bearing upon the choice of equipment : characteristics of the material, hourly production, product size or discharge setting, type and size of quarrying equipment and method of feed to the crusher.

v - Conveyor analysis is then made to determine the incline, length, feed rate, capacity, belt width, speed, HP requirements and costs.

vi - Transportation over the railroad and loading at the port is then analysed, tabulated and graphically shown. The transportation problem requires complete description of types and number of cars, locomotives, cycles, road conditions and grades, loading and unloading cycles, and costs. The present port has successfully handled over 5 000 000 T in 1961, but limitations of draft and channel width permit only carriers of up to 45 000 T, and those not too economically. The new port, now under construction, will handle ore carriers to 100 000 DWT, provide a stockpile of 1 600 000 T of iron ore, 400 000 T of coal and shipload ore at a rate of 6 000 TPH initially and 12 000 TPH in the final installation.

(c)-Result - The detailed information concerning all operations then enables the computer to tie together all constraints, specification and limitations of the total mining operation, and combining it with the economic side of the picture, an optimum operation plan then can be devised.

The final result in tabulated form will then show a cost analysis of the operations of the various mines. This of course can be made for one mine or expanded to include several mines. From this table the profit for each grade of ore can be determined, which in turn would lead to one of the ob - jectives that,of maximizing the total profit for all mines. Thus given the profit per ton of each grade of ore as P_1, P_2, P_3, etc., and G_1, G_2, G_3, etc. as tons of ore of grades 1, 2, 3, etc., the matrix is then expressed as follows:

$$P_1 G_1 + P_2 G_2 + P_3 G_3 \ldots\ldots\ldots P_n G_n = \text{maximum}$$

subject to

$$G_1 + G_2 + G_3 + \ldots\ldots\ldots G_n \leq \text{Total mining capacity}$$
$$G_2 + G_3 + \ldots\ldots\ldots G_n \leq C_2$$
$$G_3 + \ldots\ldots\ldots G_n \leq C_3$$
$$G_n \leq C_n$$

where C_1, C_2, C_3, etc. are screen capacities.

Feeding this linear programming model into the computer the number of tons of each grade to be produced can be determined to obtain the maximum profit. Having determined the amounts of various grades to be produced , the computer then calculates the crusher settings of all crushers to give a desired screen analysis at the specified production rate, feed back rate, screen sizes,etc. Similarly, train compositions and optimum speed can be determined for lowest operating costs.

5 - CONCLUSION

It can be said that, if computer techniques have given management in the U.S. and Europe a valuable tool for executive and technical decisions, these computer techniques are even more valuable to the Brazilian economy and Brazilian executives for the following reasons:

(a) - Due to the inflationary economy, sudden political changes and surprising unexpected government decisions, the evaluation of changing factors and of increased number of variable factors becomes an impossible burden for anything except high speed computor assistance, to supply the necessary information in time for sound management decisions.

(b) - The scarcity of experienced middle-rank managers and technicians point strongly to the value of greater utilization of computer techniques.

This company,as a result of planning for long-range objectives, has created a Division of Development, which also undertakes research into advanced technological methods for possible and profitable inclusion in the company's operation. These problems and their solutions, being of very specialized and complex nature, require the assistance of experts in the field. The company has in the past and will continue to call on the cooperation of consultants of international renown.

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